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(54) PROCESS FOR TREATING ORGANIC WASTES AND PRODUCT THEREOF

(71) We, COMBUSTION EQUIPMENT ASSOCIATES INC., a corporation organised and existing under the laws of the State of New York, United States of America, of 555 Madison Avenue, New York, New York 10022, U.S.A., do hereby declare the invention for which we pray that a patent may be granted to us and the method by which it is to be performed to be particularly described in and by the following statement:—

This invention relates to the handling of organic solid waste materials and more particularly to the converting of the combustible fraction of organic solid waste materials to a useable fuel material.

The disposal of organic solid wastes has become an increasingly severe problem in view of the increasing population, the concentration of populations in urban and suburban areas and the increasing number of industries generating organic solid wastes. A large fraction of such organic waste is combustible and is made up of such materials as paper, textiles, leather, rubber, yard wastes, wood, wood wastes and bark, garbage and some forms of plastics. The process of this invention is directed to the conversion of this combustible fraction of solid organic wastes into a finely divided product which can be used as a fuel or fuel supplement.

Inasmuch as it is becoming increasingly difficult to dispose of solid wastes by such previously used means as dumping and filling, a critical need has arisen to find other techniques for solid waste disposal, such techniques of necessity being those which do not create pollution problems and of preference those which do not require the expenditure of appreciable amounts of energy. Moreover, if the end product or products of the disposal process are themselves usable, the process is even more desirable.

In general, the processes more recently proposed for solid waste disposal may be classed as bulk reduction, conversion or reclamation.

Although some advances in bulk reduction (densification) have been made, each of the techniques used (baling, incineration, etc.) have inherent drawbacks including disposal of the densified material, pollution control, and the like. Conversion is generally defined as the chemical or biochemical transformation of the waste material into a useful product; and the techniques used include pyrolysis (destructive distillation or decomposition at elevated temperatures, e.g., 750—1600°F in the absence of air or other reactive or oxidizing gases), composting (aerobic conversion of cellulose waste into inert humus-like material by aerobic bacteria), hydrogenation, wet oxidation, hydrolysis, anaerobic digestion, biological fractionation and the like.

Reclamation involves the separating out from the solid waste of such materials as glass, plastics, metals, papers, textiles and the like for reuse in one form or another. However, other than some forms of papers, plastics and textiles, the combustible component of organic solid wastes which have caloric value have not been recovered. Only recently has any serious attempt been made to convert these combustible material to a form in which they could be used as a fuel.

By the process of this invention it is possible to treat the combustible fraction of organic solid wastes to form a finely divided, relatively dense fuel or fuel supplement using a relatively small amount of energy and employing known apparatus components. The resulting product is a finely divided material usable as a fuel or fuel supplement in existing combustion equipment without requiring any substantial modification. This product retains essentially all of the dry weight and caloric content of the original solid organic waste material from which it is formed.

It is therefore a primary object of this invention to provide a process for treating the combustible fraction of solid organic wastes, the processing comprising the

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embrittlement of the solid organic wastes, to form it into a fuel or fuel supplement. It is another object to provide a process of the character described which can be carried out with the expenditure of relatively little energy so that the net result of the process is an energy gain in the form of caloric fuel.

A further object is to provide a process for destroying any fibrous characteristics of the solid organic waste to increase its bulk density and improve its handling characteristics. Still another object of this invention is the providing of such a process which does not involve substantial pyrolysis, decomposition, or chemical conversion and therefore does not generate pollution control problems. It is a further object of this invention to provide a process of the character described which can be carried out in available apparatus components and which can be readily adapted to conditions prevailing within a given area to form a fuel product best suited for the area in which it is produced or to be used.

It is another primary object of this invention to facilitate the separation of the organic and inorganic constituents of solid waste by selective embrittlement of the organic fraction.

It is yet another primary object of this invention to provide a unique fuel or fuel supplement formed from the combustible fraction of solid organic wastes. It is a further object to provide a fuel of the character described which retains essentially all of the dry weight and caloric value, in a greatly densified form, of the organic material from which it was formed. It is yet another object to provide such a fuel or fuel supplement which may be stored and handled without undergoing decomposition. An additional object is to provide a fuel of the character described which may be pelletized or compacted under pressure. It is a further object to provide a fuel supplement suitable for mixing with gaseous, liquid or solid hydrocarbon fuels either prior to or during combustion.

In brief, the process of this invention comprises treating a combustible solid organic waste with mineral acid at an elevated tem-

perature under conditions to form an embrittled material, readily reducible to a finely divided form, without effecting any substantial pyrolysis, decomposition or loss in dry weight of the organic waste. The process may also include the steps of separating organic and inorganic fractions, primary gross size reduction and predrying before embrittlement and grinding, separating the fuel product from inorganics, pelletizing and mixing with other fuels subsequent to embrittlement.

The resulting fuel product is characterized as being an organic combustible material in embrittled form with caloric value and as having substantially the same weight on a dry basis, and a much greater density than the solid waste from which it was formed. It is further characterized as being suitable for use as a fuel in finely divided or pelletized form or in admixture with other fuels in different forms. If desired the material in pellet form may be compacted to a density of 40 pounds per cubic foot.

For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description taken in connection with the following drawing which is a flow diagram of the process of this invention illustrating various embodiments and modifications.

In the following detailed description of this invention, the term "combustible fraction of solid organic wastes" will be used to designate generally the materials used in the process of this invention to form the unique product of this invention. This term encompasses all materials which are of organic origin and which, when they undergo combustion in the presence of oxygen, produce caloric energy. The term therefore, includes, but is not limited to, papers, paperboards, textiles, wood, wood wastes including barks, agricultural wastes including bagasse, food wastes, yard wastes, rubber and some forms of plastics.

It will be seen from Table 1 that such materials make up the greater part of so-called solid municipal wastes.

TABLE 1
Composition of a Typical
Solid Municipal Waste

Component	% by Weight, Dry Basis	
	Total Waste	Combustible Organic Fraction
Paper & Paperboard	40.0	52.9
Yard Wastes	12.0	15.5
Food Wastes	9.3	12.1
Wood	8.4	10.9
Textiles	2.5	3.2
Plastics	2.5	3.2
Rubber	1.1	1.4
Leather	0.6	0.8
Glass	10.3	
Metal	7.1	
Dirt	5.3	

Thus substantially all of the organic material in solid wastes, e.g., in solid municipal wastes, can be subjected to the process of this invention to form a fuel. Such solid wastes typically have a moisture content of about 18%, almost all of which is associated with the combustible organic fraction. The food wastes may contain oleaginous materials in the form of, for example meat fat and oils. The presence of such materials introduces no problems in the process of this invention at the levels at which they normally occur in typical solid municipal wastes.

Inasmuch as about one-half of the solid organic wastes which can be expected to be available from an urban area comprises paper, and inasmuch as this paper constituent is usually a mixture of newsprint and corrugated board, it is possible to use a mixture of these types of papers as one model for determining the parameters of the treating step. However, the examples included herein also cover the treatment of typical food wastes, agricultural wastes and yard wastes, as well as the results of a pilot plant run on actual solid municipal wastes.

For a fuller understanding of the invention, reference is had to the following description taken in connection with the accompanying drawings, in which:

Fig. 1 diagrams the various embodiments and modifications of the process of this invention along with possible optional steps (designated by an asterisk *) which may be performed; and

Fig. 2 is a graph showing the synergistic effect of a mixture of hydrochloric and sulfuric acids on the energy required to reduce embrittled material to a desired size range;

As used throughout this application including the claims, unless otherwise evident from the context, the words "acid reactant", "acid" and "acids" are used interchangeably to designate a single acid or a mixture of acids. Where a weight or "dosage" of an acid or of an acid mixture is given, the terms refer to the acid reactant itself even though the acid reactant may be in solution.

If, as shown in the drawing the process begins with a mixed solid waste, e.g., a solid municipal waste, it will generally be expedient to begin with some form of primary size reduction such as shredding. This preliminary step may conveniently be done in such equipment as flail mills, hammer mills, shredders, shears, cage disintegrators, chippers, cutters, disk mills, grinders, hoggers, and rasp mills.

The physical separation of the organic combustible fraction from the mixed waste may be accomplished by one or more of several

different known techniques including separation procedures based upon differences in such physical characteristics as size, shape, specific gravity, brittleness, elasticity, color reflectance, magnetic susceptibility, electric conductivity, absorption of electromagnetic radiation and radioactivity. Techniques and apparatus for using these characteristics to sort out such nonorganic materials as glass, metals, dirt, and the like are known and described in the literature. (See for example "Solid Waste Treatment Technology" by Alex Hershaft in *Environmental Science & Technology*, Vol. 6, No. 5 pp 412-421 (1972).)

The separation of the organic and inorganic fractions may be postponed until after the embrittled material is ground, thus making it possible to readily separate the powdered organic fraction from the inorganic fraction. In some cases, the waste pieces making up the inorganic fraction may be used as all or part of the grinding medium.

It is, of course, within the scope of this invention to begin with solid organic waste material which requires no sorting or separating from other waste materials. In such cases, it may be desirable or necessary to perform a size reducing step using appropriate equipment from the list given above. Thus for example hammermills, shredders or grinders can be employed to reduce such materials, as paper, wood, textiles or food wastes to the desired degree of comminution. In like manner, it may be desirable to further reduce the size of the combustible organic fraction from mixed wastes subsequent to the separation of this fraction from a waste mixture.

The actual size of the waste material fragments which are subjected to the embrittlement treatment will depend upon the nature of the organic material as well as the manner and apparatus used to effect the embrittlement treatment. Thus, for example, it will generally be preferable to reduce the waste to a size amenable to ready handling in the equipment used in the process.

The embrittlement step, as will be described in more detail below, comprises treating the organic waste material with mineral acid in a controlled temperature range for a time sufficient to effect the embrittlement. As noted, inorganic wastes may be separated from the organic wastes either prior to or subsequent to the embrittling.

In the process of this invention it is possible to treat waste materials as received without removing moisture contained therein. However, predrying may be desirable to permit the venting of the water vapor thus removed directly into the atmosphere without creating pollution problems such as might be generated if drying were carried out during or after treatment with acid.

If drying is to be done prior to embrittlement in a separate reactor, it can be done in

such apparatus as a cocurrent or counter-current direct or indirect fired dryer. It is also of course, possible to combine the predrying step with one of the size reducing steps, using heated surfaces and/or the circulation of a hot gas within or through the apparatus in which size reduction is accomplished. It is also possible to combine the drying step with the embrittling step, particularly if embrittling is carried out by heating followed by acid treatment. If drying is made part of the total embrittling step (heating and acid treatment) then the moisture recovered may be vented directly to the air if provision is made to remove the acid therefrom prior to such venting. Therefore, it may be preferable to predry, if and when this step is necessary, prior to the acid treatment. Alternatively, an acid absorber may be used. Such an absorber is particularly useful where materials which generate a volatile acid may be encountered.

Other than any plastic materials and rubbers which may be processed, most of the solid organic wastes treated in this invention are generally fibrous in nature, a fact which means that it is not possible to increase the bulk density of solid organic wastes by grinding alone without the expenditure of excessive amounts of energy. However, when these materials are embrittled using a combination of heat and acid according to this invention, the resulting embrittled material may be readily ground with little expenditure of energy to form a product with a bulk density of from about 20 to 30 pounds per cubic foot, compared to 3 to 6 pounds per cubic foot for the shredded untreated waste. This bulk density of the treated material may be further increased up to as much as 70 pounds per cubic foot with compaction under pressure.

It may be postulated that the embrittlement effects some depolymerization of the organic material as evidenced by the loss of its fibrous nature. Embrittlement by the present process does not, however, involve pyrolysis, decomposition or combustion to any significant extent as evidenced by the fact that there results no appreciable loss of dry weight, no significant production of identifiable decomposition or degradation products such as acetone, alcohols and the like and no identifiable products of combustion such as char, and combustion gases. There is, moreover, no appreciable change in the carbon/hydrogen/oxygen ratios of the organic material after embrittlement.

As will be seen from Fig. 1, there are several embodiments and modifications possible in the embrittlement step. Before discussing each of these in detail, it will be convenient to set forth the operational parameters, e.g., temperatures and acid concentrations, which apply to all of these embodiments and their modifications.

Since embrittlement does not involve any appreciable pyrolysis, thermal degradation or combustion, the conditions under which this step is performed should be such as to prevent such reactions from occurring to any appreciable extent. Although temperatures may range between 212° and 550°F, it is preferable to use temperatures in the heat treating which range between about 250° and 350°F. The use of temperatures not above about 350°F makes it possible to use hot air as the means for heating the material during embrittlement. If temperatures much in excess of 350°F are used, then care must be taken to use an atmosphere of reduced oxygen content to prevent combustion of the organic material. Thus, for maximum yield, the combination of temperature and oxygen content of the surrounding atmosphere must be such that no significant combustion or pyrolysis will occur during embrittlement.

The heating of the organic waste material may be accomplished by direct heat transfer from a hot gas, e.g., hot flue or stack gases or hot air, to the material. It may also be accomplished by indirect heat transfer from a heat transfer fluid through any suitably designed heat exchanger. If a grinding step is combined with the embrittling step, then the grinding medium (e.g., steel, ceramic balls or inorganic waste) or the walls of the apparatus in which grinding is effected may be heated and serve as the only or as one source of heat. It is, of course within the scope of this invention to employ any suitable combination of direct and indirect heating procedures.

The acid used in the embrittling step is mineral acid (e.g. HCl, H₂SO₄, HNO₃ or H₃PO₄) or what may be termed a precursor of such a mineral acid. Among the compounds which may be regarded as acid precursors are strongly acid metal salts of a mineral acid, e.g., ZnCl₂ or FeCl₃ or an inorganic acidic gas, e.g., SO₃, NO₂ or N₂O₅.

The acid or acid precursor may be used in gaseous form (gaseous HCl or SO₃, for example) or in liquid form (dilute aqueous solution of H₂SO₄ or of HCl or alcoholic solution of ZnCl₂, for example). The use of a volatile acid (e.g., an acid having a boiling point below the temperature used) such as HCl gas may have advantages in a batch process and in those embodiments of the embrittling step where heating precedes acid treating (I of Fig. 1) or where heating and acid treating are carried out simultaneously (III of Fig. 1). The use of a nonvolatile acid (i.e., an acid having a boiling point above the temperature used) such as a dilute aqueous solution of H₂SO₄ may have advantages in a continuous process and in that embodiment of the embrittling step where heating follows acid treating. Thus in this latter case, the organic material, after being sprayed with

or soaked in the acid solution, may be pressed to 50 to 70% dryness or otherwise treated to remove at least a portion of the water absorbed in the acid treatment before heating. Some energy will of course be required in the subsequent drying of the resulting moist material.

When a volatile acid is used and is carried in a treating gas, the amount of residual acid in the final product is not directly related to the concentration of the acid in the treating gas. Therefore, there is a wide latitude possible in the concentration of the volatile acid in the treating gas, and the optimum concentration may readily be determined consonant with such operational parameters as temperature, time of exposure of the waste to the gas, form of gas-solids contacting and materials from which the treating apparatus is formed. Exemplary of such concentrations is the use of from about 0.1 to 5% by volume of HCl in air when paper is treated. Normally, the higher concentrations are preferred since the embrittlement will generally proceed more rapidly.

In the use of a nonvolatile acid, e.g., an aqueous solution of H₂SO₄, the acid pickup in the organic waste is proportional to the acid concentration in the solution. It is therefore preferable in this embodiment of the embrittling step to use acid solutions ranging in concentrations between about 0.1 and 5% by weight.

In a preferred embodiment of the process of this invention the acid reactant is a combination of hydrochloric and sulfuric acids applied separately or as a mixed aqueous solution sprayed onto the solid waste material at any of the suitable points in the process. By using a mixture of these two acids it is possible to enhance the embrittlement of the organic fraction of municipal waste, the enhancement being directly measurable in terms of a marked decrease in the energy required to reduce the embrittled material to a desired size range. The use of a mixture of hydrochloric and sulfuric acids has a number of advantages in addition to the very important reduction in energy required. Among these advantages are a decrease in residual chlorides in the product, a reduction in the amount of acid reactant which must be handled, a reduction in the cost of the acid reactant, and the ability to attain a final product having a particle size range which may be below that attainable with the use of hydrochloric acid alone for the same energy input.

Although it is not known precisely why the use of sulfuric acid in conjunction with the hydrochloric acid has what may be considered a synergistic effect, it seems reasonable to postulate that the sulfuric acid may increase the mobility of the added hydrochloric acid by decomposing chlorides which form, neutralize potential chloride-forming salts, or

perform a combination of these two functions.

The length of time during which the organic material is exposed to the embrittling step will vary, depending upon the embodiment of this step used, the size of the waste material being treated, and the conditions of treatment, i.e., temperature and acid dosage (time and concentration). The time must be at least sufficient to bring the material up to temperature and to effect embrittlement. Normally, when heating and acid treatment are done simultaneously, this time will not be in excess of about 30 minutes; and if the higher temperatures and higher acid concentrations are used, embrittlement may be accomplished in only a few minutes, e.g., about 5 minutes. For any given size of organic material, taken in conjunction with the operational parameters chosen, it is a simple matter to choose an optimum time to give a product having a desired proportion of embrittled, friable product. Thus, it may be desirable to carry out embrittlement until only a predetermined fraction of the material being processed has reached the desired stage of embrittlement and to recycle that fraction which has not.

Some of the components making up the solid organic wastes treated have water associated with them. This water may be chemically bonded or mechanically held within the organic mass and its content in the embrittled material resulting from the combined heat and acid treating should not exceed about 10% by weight and preferably the embrittled product should be as dry as possible for ease of grinding.

The use of flue or stack gases as a means for directly heating the material during embrittlement introduces the possibility of introducing steam (water vapor as contrasted to water associated with the organic waste material) into the embrittling step. It has been found that the presence of such steam does not materially affect the embrittlement of the organic material.

As indicated in the drawing, the embrittling step may be carried out in one of several ways. If as in embodiments I and II, heating and acid treating are to be done separately, then heating may be accomplished in such equipment as a cocurrent or countercurrent direct or indirect fired dryer, a fluid bed, a multiple hearth roaster or a multi-deck digester. If a volatile acid is used, such as gaseous HCl, this may be applied in any suitable gas-solid contacting device such as a cocurrent or countercurrent flow mixer to the heated material. If a nonvolatile acid is used, such as an aqueous solution of H_2SO_4 , it may be sprayed on as the waste material is moved on a belt conveyor; or it may be applied by moving the waste material through an acid bath, in which case the excess acid may be removed by pressing for example through rollers.

If heating and acid treatment with a volatile acid are to be carried out simultaneously, then this combined step may be done in a rotary dryer into which a stream of HCl gas is introduced.

Since it is also possible in some of the embrittling equipment to apply a degree of attrition sufficient to pulverize or grind the embrittled material, the step of grinding may be combined with embrittlement using, for example, a tumbling device such as a ball mill.

If grinding is to be carried out as a separate step it may be done in such apparatus as ball mills and pulverizers or between abrasive surfaces. Since the organic material is embrittled, grinding, whether it is carried out separately or as part of the embrittling step, requires relatively little energy compared with that required for grinding the untreated solid organic waste material to the same degree of fineness. This fact is one of the principal energy conserving aspects of the process of this invention.

The particle size of the ground embrittled fuel product may vary over a relatively wide size range, depending upon such factors as type and degree of grinding. Generally, the greater portion of the material will pass a 40-mesh screen (i.e., about 0.0165 inch or smaller) and a considerable portion will pass a 200-mesh sieve (i.e., about 0.0029 inch or smaller). The larger particles which may not be completely embrittled may be recycled to the embrittling step.

If separation of the product ground material is necessary it is preferably done by air classification, although screening may be used. In this optional step it is possible to sort out organic fragments which have not been completely embrittled as well as nonorganic material (e.g., small pieces of metal, glass, etc.) from the fuel product. The incompletely embrittled organic fragments may be recycled back to the embrittling apparatus.

If the waste material being treated is a combination of inorganic and organic fractions, i.e., no separation or only partial separation of these fractions having been effected prior to the embrittling treatment, then it will be necessary to separate out the non-embrittled fraction subsequent to grinding. This nonembrittled fraction will contain the inorganics and may contain some non-embrittled or partially embrittled organic wastes. The nonembrittled or partially embrittled organic materials may be recycled to the embrittlement treatment of heat and acid to complete their treatment. It should be noted that in such a case where there is no separation of the combustible and noncombustible fractions of the waste prior to embrittlement, at least a portion of the noncombustible fraction (e.g., metal and glass objects) can be used as the grinding medium.

As shown in Fig. 1, it is also possible to perform embrittlement (heating and acid treating) and grinding in a liquid fuel, such as for example in a No. 6 fuel oil. This modification is particularly applicable to those cases where complete embrittlement is achieved and no sorting or classification is necessary after grinding. Thus, for example, where the organic material is essentially all paper, it is possible to ensure complete embrittlement and grind all of the product to a desired particle size range in a liquid fuel to form a slurry of the fuel product directly in the liquid fuel. This may be done, for example, by ball milling the paper in hot fuel oil to which acid has been added.

The fuel product which results from grinding, and classification if required, is a fine powdery material. As will be apparent from the examples given, the product retains essentially all of the dry weight of the original solid organic waste from which it was made and has essentially the same carbon/oxygen/hydrogen ratios that were present in the solid untreated organic waste. Little, if any, caloric value is lost in the embrittlement. The embrittled product when formed by treatment with HCl contains only a small amount of

chloride ions, e.g., typically 0.1 to 0.2% by weight, although it may be up to 0.6%. That product formed by using H_2SO_4 will contain sulfate ions essentially in direct proportion to the quantity of acid pickup in the treating.

The fuel product may be burned in finely divided form as a primary fuel without the addition of any other fuel. The fuel product may also be pelletized, with or without the use of a binder such as water, starch, wax and mineral oil, in standard pelletizing equipment. Finally, the fuel product may be compacted under pressure to form a highly dense material.

The fuel product of this invention may also be mixed with gaseous, liquid or solid fuels (referred to hereinafter as primary fuels) to serve as a secondary fuel. Such mixing may be prior to or during combustion. Thus, for example, it may be entrained in natural gas or fed simultaneously with natural gas through separate injection apparatus into a combustion chamber; it may be slurried with fuel oil or cofired therewith; and it may be physically mixed with powdered coal or cofired with it.

The data in Table 2 illustrate the effect of adding a fuel product of this invention formed from paper to No. 6 fuel oil.

TABLE 2

Fuel Composition Btu Contributed by				Btu/lb Total Fuel	Btu Based on 1 lb Fuel Oil
Fuel Oil	Solid Fuel Product	Fuel Oil	Solid Fuel Product		
—	100	—	8,000	8,000	
100	—	19,588	—	19,588	
85	15	16,650	1,200	17,850	20,788
60	20	15,670	1,600	17,270	21,188

These data indicate that the fuel product contributes caloric value to the fuel oil. In such a mixture, each fuel constituent contributes its caloric value in direct proportion to its weight fraction.

The fuel product of this invention may be added to fuels other than the so-called fossil fuels. These other fuels include, but are not limited to, combustible hydrocarbon wastes, waste fuels, waste solvents (with or without water) and sewage sludge. The amount of fuel product added to a fossil fuel or any other type of fuel will depend upon the caloric value desired of the mixed fuel, a property

which can readily be measured by known techniques.

The invention is illustrated in the following examples.

Example 1.

Newsprint was used as a model for a solid organic waste material and the embrittling step was carried out in a stainless steel tube reactor 2½ inches i.d., and 19 inches long. Ten grams of the newsprint in the tube was exposed to hot air containing HCl gas circulated through the tube at a flow rate of one liter/minute. A standard grind test was

devised to determine the effectiveness of the process and was used in all of the following examples. In this test a one-quart paint can loaded with 600 grams of quartz pebbles about one inch in diameter was charged with the total reactor product and shaken on a commercial paint shaker for ten minutes. The resulting powder was examined for the presence of unground flakes and was then screened to determine what percentage passed

through a 40-mesh screen (420 microns or smaller) and what percentage passed through a 200-mesh screen (74 microns or smaller).

The yield of product based on the weight of the original solid organic waste including moisture (normally about 6%) was determined and the densities of the uncompacted and compacted products were measured.

Data thus obtained for newsprint samples are summarized in Table 3.

TABLE 3

Fuel From Newsprint

Temp. °F	Time Min.	HCl Dosage*	Yield %	Grind Test % Through		Density Lbs./ft ³	
				40- Mesh	200- Mesh	Uncom- pacted	Com- pacted
300-350	5	1.8	94	99	80	25	52
300-350	10	3.6	91	98	50	26	55
350-400	5	1.8	94	98	70	25	54
350-400	10	3.6	86	98	75	28	50

*total quantity of HCl, based on sample weight, passing through reactor.

Since the yield figures are based upon a newsprint having a moisture content in equilibrium with the atmosphere (about 5 to 6%) it will be seen that when this moisture content is added to the yield figures that yields as high as about 99% were obtained.

sisted of soaking pieces (about 1×4 inches) of corrugated board in a dilute aqueous solution of H₂SO₄. Subsequent to a two-minute soak, the corrugated board pieces were withdrawn and the excess water was pressed out by pressing between two blotters. Then the samples were heated in air at 350°F for 10 minutes before subjection to the standard grind test described in Example 1. The results for two samples are summarized in Table 4.

Example 2.

The acid treatment in this example con-

TABLE 4

Fuel From Corrugated Board

Sample No.	H ₂ SO ₄ Dosage*	Grind Test % Through	
		40- Mesh	200- Mesh
1	1.4	80	55
2	2.5	99	62

*weight % pickup.

Example 3.
A mixture of about 75% by weight newsprint and 25% corrugated board, cut to pieces of about $\frac{3}{4} \times \frac{3}{4}$ inch to accommodate the equipment used, was treated to serve as a model of organic waste. A ball mill, having different types of grinding media, was heated to 400°F before ten grams of the paper waste was introduced. HCl gas was bled into the ball mill during treating and the acid dosage was varied. The data from 5 runs using various acid dosages, grinding media, and grinding times are summarized in Table 5.

TABLE 5

Fuel From Paper Mixture

Type	Grinding Medium		Total HCl Dosage	Time Min.	Grind Test % Through		Density Lbs/ft ³	
	Bulk Lbs/ft ³	Units lb			40-Mesh	200-Mesh	Uncompacted	Compacted
3/4" ceramic balls	104	45	5.5	15	82	10	21	42
do	104	45	11.0	30	97	50	24	49
3/8" steel balls	312	126	5.5	15	92	60	30	71
do	312	126	11.0	30	98	70	28	67
Inorganic Trash	62		5.5	15	55	15	—	—

Example 4.
Papers other than newsprint and corrugated board were processed in the laboratory reactor, described in Example 1, using hot air at 375°F, and an HCl dose of 1.5% by paper weight, for four minutes. The paper samples had a moisture content in equilibrium with the atmosphere. The data of Table 6 illustrates the applicability of the process of this invention to these widely varying types of paper.

TABLE 6
Fuel From Waste Papers

Type of Paper	Thickness Inch	Yield %	Ground Test % Through 40-Mesh
Soap carton (heavy boxboard)	.029	83	98
Milk carton (poly- ethylene coated bleached kraft)	.018	86	92
Beer carrier (heavy kraft)	.016	91	35-70
Coated magazine (free sheet)	.004	95	85
Coated magazine (ground-wood base)	.002	90	99
Office Bond	.003	95	100
Grocery bags (light kraft)	.007	91	85
Foil-lined juice paper cans	.030	90	20-40

Example 5.

5 Miscellaneous items which might be found in solid municipal wastes were treated in the laboratory reactor (Example 1) by circulating air at 375°F, containing 2¼% by volume HCl, for 5½ minutes at a flow rate of one liter/minute. Since successful grinding requires a moisture content of less than about

10% by weight, the items of this example, representative of garbage and trash, were pre-dried at 220°F to essentially 0% moisture and then allowed to regain equilibrium moisture (5-10% by weight) before embrittlement. These materials were successfully 15 formed into a product as shown by the data of Table 7.

TABLE 7

Fuel from Miscellaneous Organic Wastes

Material	Yield %	Grind Test % Through 40-Mesh
Leaves and pine needles	90	99
Evergreen clippings	91	99
Preshredded twigs		70
Apple core	80	100
Banana skin	80	95
Ham slice	96	80
Citrus peels	93	95
Melon rinds	92	95
25% beef trimmings. }	89	99
75% newsprint }		

Example 6.

5 A sample of shredded municipal solid waste was charged to a 2' x 10' rotary dryer fired with hot flue gas which entered the dryer at about 600°F. The sample was initially dried and heated to 300°F (as measured within the dryer) at which time HCl gas in a concentration of about 1 volume % was added

to the flue gas used for heating the reactor. The addition of the acid gas was continued for about 20 minutes. It was observed that the mechanical abrasion in the rotary dryer was adequate to pulverize a significant portion of the organic fraction to small flakes. The data in Table 8 illustrate the results obtained by grinding the heavy materials found in the dryer after removing therefrom. 10 15

TABLE 8

Treatment of Municipal Waste

Material ground	Grind Test % Through	
	40-mesh	200-mesh
Large-pieces corrugated board	75	30
Mixed organic waste	80	60

Example 7.

20 Ten grams of virgin newsprint was treated with HCl gas in the laboratory reactor described in Example 1. The HCl dosage was 3.6% (total quantity of HCl, based on sample

weight, passing through the reactor), the time of the embrittlement was ten minutes and the temperature ranged between 300 and 325°F. The product, amounting to a 92% weight yield, was subjected to the grind test described 25

in Example 1 and it was found that 98% of the resulting powdered embrittled material passed a 40-mesh screen and 60% passed a 200-mesh screen.

- 5 The product and a control sample of the original virgin newsprint were analyzed by standard microanalytical techniques to determine the percentages of carbon, hydrogen, chlorine and oxygen present. The control sample was found to have 5.8% by weight moisture and the embrittled product 1.7%. The results of these analyses are summarized in Table 9.

TABLE 9

Elemental Analyses, % By Weight
(Dry Basis, Average of Two Samples)

Element	Control Sample	Embrittled Product
Carbon	48.54	48.04
Hydrogen	6.45	6.04
Chlorine	0.04	0.30
Oxygen	45.03	45.62

- 15 These figures show that no appreciable change in the carbon/hydrogen/oxygen ratio is effected by embrittlement. They also show that no appreciable decomposition or pyrolysis has taken place. The chlorine pickup was about 0.26% by weight.

Example 8.

- 25 Since the most realistic measure of the degree of embrittlement attained is the energy required to grind an embrittled product to a specified particle size, this form of measurement was used to determine the effect of adding sulfuric acid to hydrochloric acid. In these measurements, those other factors, such as temperature and moisture content which are known to affect embrittlement were maintained constant. The results are shown in the graph of Fig. 2.

- 30 Samples of a partially predried (e.g. about 6% moisture) solid municipal waste material were first treated with dosages of hydrochloric acid alone equal to 3%, 1% and 0.4% by weight of the waste material and heated to 300°F. Subsequent to such acid treatments the energy, expressed as KWH/ton of untreated waste (dry basis) required to grind the acid-treated material to a size where about 75—80% of the ground material would pass a standard 20-mesh (American Standard) sieve was determined. The resulting energy

requirements were 4.3, 26 and 100 KWH/ton for the material treated with dosages of 3, 1 and 0.4% HCl, respectively. When an acid dosage of a combination of 0.5% sulfuric acid and 0.4% HCl (based on the weight of solid waste material subsequent to drying) was added to the waste material as the embrittling agent, the resulting embrittled product required only 6.5—7 KWH/ton to obtain the desired particle size, a reduction by a factor of about 15 in the energy requirement compared to the case where 0.4% HCl alone was used or a factor of about 4 if a comparison is made at essentially the same acid level. Likewise, a combination of about 1% by weight HCl and about 0.5% H₂SO₄ can produce a fuel product with essentially the same degree of embrittlement attained by using 3% by weight HCl alone.

Although dosages of H₂SO₄ greater than 0.5% by weight of the organic waste material may be used, it appears that dosages in excess of about 1 to 1.5% yield no added or increased benefits. Moreover, it is generally preferred to use a minimum amount of HCl, e.g., up to about 0.5 to 2% by weight, to minimize the amount of residual chlorides and reduce the cost of the final product. Therefore, a preferred acid reactant is a mixture of HCl and H₂SO₄ wherein the weight ratio of HCl to H₂SO₄ ranges from about 1 to 10 to about 4 to 1 and the total amount of acid does not exceed about 5% of the weight of the waste material being treated. It should be noted that the designations HCl and H₂SO₄ refer to the actual reactants which are usually added as more or less dilute solutions for convenience and uniform distribution.

The optimum acids ratio and the dosage will vary with the compositions of the solid waste under treatment. In general, the saving in energy requirement is balanced against the cost of the acid added and the quantities of residual chlorides to determine the total acid to be added and the ratio of HCl to H₂SO₄. Curves such as shown in Fig. 2 can readily be established for any specific solid waste composition so that optimum acid ratios and dosages can be determined.

It will thus be seen that the process of this invention makes it possible to form a useful fuel from solid organic wastes. By embrittling the organic wastes prior to size reduction the amount of energy to produce a usable material is materially reduced over that which would be required if the material were not embrittled. The fuel thus produced may be used in many different ways.

WHAT WE CLAIM IS:—

1. A process for embrittling the solid organic waste fraction of a solid waste material characterized by the treating of said organic waste fraction with mineral acid and at elevated temperature, the conditions of said treat-

- ing being such as to form an embrittled material, readily reducible to a finely divided form, without any substantial pyrolysis, any substantial decomposition or any substantial loss in dry weight of said solid waste fraction.
- 5 2. A process in accordance with claim 1 wherein said waste is solid municipal waste.
3. A process in accordance with claim 1 wherein said solid waste contains wood wastes.
- 10 4. A process in accordance with claim 1 wherein said solid waste contains agricultural wastes.
5. A process in accordance with claim 1 wherein said treating is accomplished at a temperature ranging between 212 and 550°F.
- 15 6. A process in accordance with claim 5 wherein said treating is accomplished at a temperature ranging between 250 and 350°F.
7. A process in accordance with claim 1 wherein said treating comprises exposing said waste first to said acid and then to said elevated temperature.
- 20 8. A process in accordance with claim 1 wherein said treating comprises exposing said waste to said acid and elevated temperature simultaneously.
- 25 9. A process in accordance with claim 1 wherein said treating comprises exposing said waste first to said elevated temperature and then immediately to said acid.
- 30 10. A process in accordance with claim 1 wherein said acid is in the form of a gas.
11. A process in accordance with claim 10 wherein said acid is HCl gas.
- 35 12. A process in accordance with claim 1 wherein said acid is in the form of a solution.
13. A process in accordance with claim 12 wherein said acid is H_2SO_4 and said solution is an aqueous solution.
- 40 14. A process in accordance with claim 1 wherein said acid is a mixture of at least two mineral acids.
15. A process in accordance with claim 1 wherein said acid is a mixture of hydrochloric acid and sulfuric acid.
- 45 16. A process in accordance with claim 1 wherein the quantity of sulfuric acid mixed with hydrochloric acid is such as to effect a substantial reduction in the energy required to reduce embrittled material to a desired size range as compared with that required for hydrochloric acid alone when used in an amount equal to the total amount of the mixture of acids.
- 50 17. A process in accordance with claim 15 wherein the weight ratio of hydrochloric acid to sulfuric acid is in the range of 1 to 10 to 4 to 1.
18. A process in accordance with claim 17 wherein the total amount of acid dosage does not exceed 5% of the weight of the organic waste fraction being treated.
- 60 19. A process in accordance with claim 1 wherein said treating at elevated temperature comprises contacting said waste with a hot gas.
20. A process in accordance with claim 19 wherein said hot gas is flue gas.
21. A process in accordance with claim 19 wherein said hot gas is air.
- 70 22. A process in accordance with claim 19 wherein said hot gas contains said mineral acid in vapor form.
23. A process in accordance with claim 1 wherein said treating at elevated temperature comprises contacting said waste with a heated surface.
- 75 24. A process in accordance with claim 23 wherein said heated surface is a grinding medium.
25. A process in accordance with claim 1 wherein said treating of said waste is carried out in a liquid fuel medium.
- 80 26. A process in accordance with claim 25 wherein said fuel medium is fuel oil.
27. A process for forming a combustible fuel from solid municipal waste containing an organic waste fraction and an inorganic waste fraction, comprising the steps of
- 85 (a) treating the solid organic waste fraction of solid municipal waste with mineral acid and elevated temperature under conditions to form an embrittled material which is thereby readily reducible to a finely divided form without effecting any substantial pyrolysis, any substantial decomposition or any substantial loss in dry weight of said waste component; and
- 90 (b) reducing the resulting embrittled material to a finely divided form.
28. A process in accordance with claim 27 including the step of reducing the size of the components forming said solid, municipal waste.
- 100 29. A process in accordance with claim 27 including the step of separating said organic waste fraction from said municipal waste prior to said treating step.
- 105 30. A process in accordance with claim 27 including the step of separating said organic waste fraction from said municipal waste subsequent to said treating step.
- 110 31. A process in accordance with claim 27 including the step of predrying said organic waste fraction prior to said treating step.
32. A process in accordance with claim 27 including the step of adjusting the moisture content of said embrittled material to not more than 10% on a dry weight basis just prior to said step of reducing said embrittled material to a finely divided form.
- 120 33. A process in accordance with claim 27 including the step of classifying said embrittled material subsequent to said step of reducing said embrittled material to a finely divided form thereby to separate out particles of said solid organic waste which are not embrittled.
- 125 34. A process in accordance with claim 33 including the step of returning at least a portion of said particles which are not embrittled to a second treating step.
- 130

35. A process in accordance with claim 27 wherein said step of reducing said embrittled material to a finely divided form comprises grinding.
- 5 36. A process in accordance with claim 35 wherein said grinding is effected by milling with a grinding medium.
37. A process in accordance with claim 36 wherein said grinding medium comprises said inorganic waste fraction.
- 10 38. A process in accordance with claim 27 including the step of pelletizing said embrittled material in finely divided form.
39. A process in accordance with claim 27 including the step of compacting said embrittled material in finely divided form.
- 15 40. A process in accordance with claim 27 including the step of mixing said embrittled material in finely divided form with a primary fuel.
- 20 41. A process in accordance with claim 40 wherein said primary fuel is in fluid form.
42. A process in accordance with claim 41 wherein said primary fuel in fluid form is a liquid and said embrittled material is slurried therein.
- 25 43. A process in accordance with claim 42 wherein said primary fuel is fuel oil.
44. A process in accordance with claim 42 wherein said primary fuel is combustible hydrocarbon waste.
- 30 45. A process in accordance with claim 42 wherein said primary fuel is sewage sludge.
46. A process in accordance with claim 41 wherein said primary fuel in fluid form is a gas and said embrittled material is entrained therein.
- 35 47. A process in accordance with claim 40 wherein said primary fuel is a solid fuel.
- 40 48. A process in accordance with claim 47 wherein said solid fuel is powdered coal.
49. A combustible fuel material when made by the process of claim 1 characterized as being an organic solid embrittled waste material having substantially the same carbon, hydrogen and oxygen ratios and substantially the same weight on a dry basis as said organic solid waste prior to embrittlement.
- 45 50. A combustible fuel material characterized as being organic solid waste which has been embrittled and reduced to finely divided form, said waste having substantially the same carbon, hydrogen and oxygen ratios and substantially the same weight on a dry basis as said organic solid waste prior to embrittlement.
- 50 51. A combustible fuel material in accordance with claim 50 further characterized as having a density of at least 20 pounds per cubic foot.
- 55 52. A combustible fuel material in accordance with claim 50 being further characterized as being in pellet form.
53. A combustible fuel material in accordance with claim 50 being further characterized as being compacted to a density of at least 40 pounds per cubic foot.
- 65 54. A combustible fuel material comprising (a) a primary fuel; and (b) a secondary fuel admixed with said primary fuel, said secondary fuel being characterized as an organic solid waste which has been embrittled and reduced to finely divided form, said waste having substantially the same carbon, hydrogen and oxygen ratios and substantially the same weight on a dry basis as said organic solid waste prior to embrittlement.
- 70 55. A fuel material in accordance with claim 54 wherein said primary fuel is in fluid form.
56. A fuel material in accordance with claim 55 wherein said primary fuel is a liquid and said secondary fuel is slurried therein.
- 75 57. A fuel material in accordance with claim 56 wherein said primary fuel is fuel oil.
58. A fuel material in accordance with claim 56 wherein said primary fuel is combustible hydrocarbon waste.
59. A fuel material in accordance with claim 56 wherein said primary fuel is sewage sludge.
- 80 60. A fuel material in accordance with claim 55 wherein said primary fuel in fluid form is a gas and said secondary fuel is entrained therein.
61. A fuel material in accordance with claim 54 wherein said primary fuel is a solid fuel.
- 85 62. A fuel material in accordance with claim 61 wherein said primary fuel is powdered coal.
63. A process according to claim 1 for embrittling the solid organic waste fraction of a solid waste material substantially as hereinbefore described with reference to the accompanying drawings.
- 90 64. A process according to claim 27 for forming a combustible fuel from solid municipal waste containing an organic waste fraction and an inorganic waste fraction substantially as hereinbefore described with reference to the accompanying drawings.
- 95 65. A combustible fuel material according to claim 49 or 50 substantially as hereinbefore described with reference to the accompanying drawings.
- 100 105 110 115

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FIG. 1

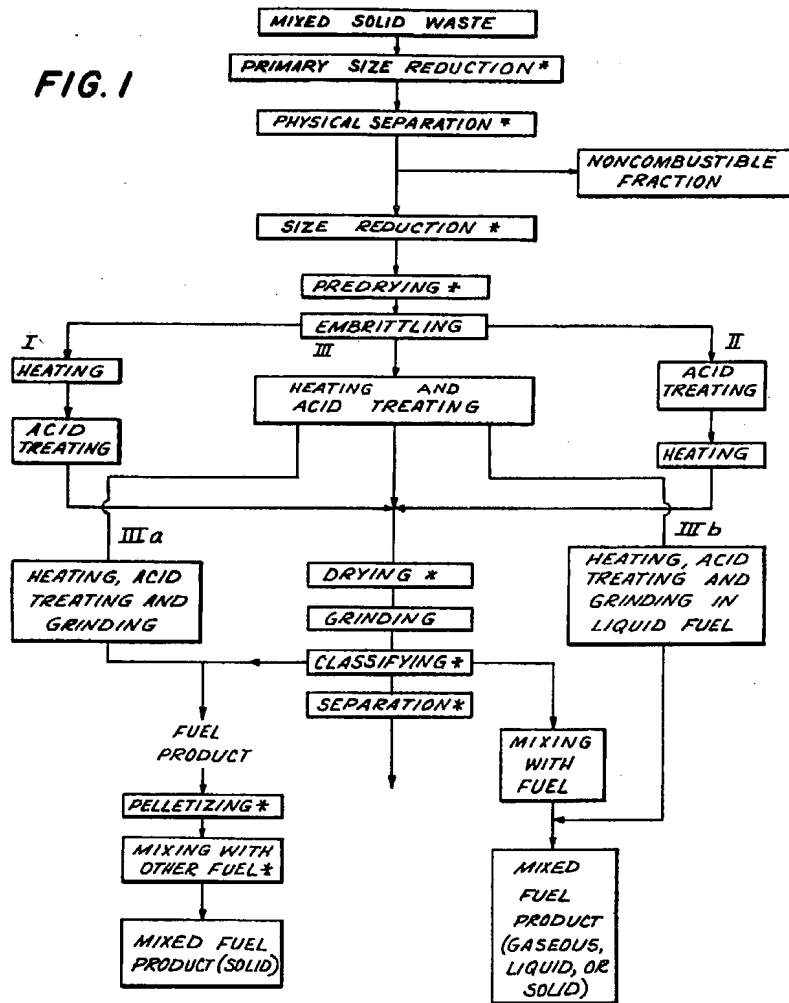


FIG. 2

